

Emailed response to Mr. Len Damiano of EBTRON from Mark Hydeman of Taylor Engineering, October 21, 2003

From: Mark Hydeman <mhydeman@taylor-engineering.com>
To: damiano@ebtron.com
Date: 10/21/2003 9:37 AM
Subject: Response to your October 14th letter to the CEC regarding the DCV requirement
CC: Bryan Alcorn balcorn@energy.state.ca.us, Bill Pennington bpennington@energy.state.ca.us, jahbata@aol.com, "Steven T. Taylor" staylor@taylor-engineering.com

Dear Mr. Damiano:

I am writing on behalf of the California Energy Commission in response to your letter of October 14th, 2003 on the proposed demand controlled ventilation requirement in the 2005 version of the Title 24 standard. I am the author of that proposed requirement and a consultant to the CEC in the development of the HVAC requirements for the Standard. Attached for your review are two documents: 1) The current proposed requirement (from the 45 day language) and 2) the study that we undertook to develop this requirement (note the DCV study starts on Page 12).

Reading your letter it is clear that you have not reviewed our study. Note that this proposal merely refines the existing DCV requirement (from the 2001 version of Title 24 and the 2001 version of ASHRAE Standard 90.1 section 6.2.3.8) and tightens performance requirements for the implementation of DCV in the Standard.

I will try to address each of the issues that you raised as it applies to our study and the proposed requirement.

Page 1, PP2: You state, "It seems that it is only when CO₂ is compared to extremely energy inefficient system designs that this method provides calculated savings. This includes published examples using CAV and VAV with reheat, outside of the currently allowable system designs under the latest energy codes. There are significant risks of allowing intakes to close completely and thereby achieve reductions in energy consumption. There are also pressurization control implications that are not considered and that will conflict with strategies that use CO₂ for ventilation control exclusively."

The study (attached) documents that we compared code complying packaged single zone CAV units for the purposes of developing this standard. The requirement is limited to this application. Pressurization control is a

factor with all economizer systems and is covered under section 144 of the existing standard. Intakes are never allowed to close completely during normally occupied times per the Section 121 ventilation requirements. For most spaces (see Table 1-F) the minimum ventilation rate even with DCV controls is 0.15 cfm/ft².

Page 1, PP3: You state, "CO₂-based Demand Control Ventilation schemes should be limited to those which directly verify intake rates..."

This is true for all VAV systems. The standard is addressing this through performance verification measures that address certification of ventilation for VAV systems and DCV systems.

Page 1, last paragraph: You state "This position can actually backfire when the method referenced over-ventilates due to the errors experienced in CO₂ application, measurement, sensing or calculation."

The DCV requirements in the standard only allow the sensor to reset the minimum ventilation between the floor provided by Table 121-A and the ceiling provided by section 121 (b) 2. Sensor accuracy and calibration is also covered in the proposed requirement with a guaranteed minimum accuracy of 75ppm over a 5 year period. Several manufacturers now certify their sensors to hold this accuracy over the life of the device.

Your concept of using CO₂ control to reset direct measurement of OSA (page 2 paragraph 3) is permitted under the proposed requirement but is not required. There are many studies (several referenced in the attached report) that document CO₂ as being effective means for measuring occupant borne contaminants. This is recognized in ASHRAE 62.

In summary I believe that you will find your concerns already addressed by our study and the proposed requirement. In the process of developing this requirement we corresponded both with Peggy Jenkins and Dr. Federspiel and have address the concerns that they raised. We appreciate your input and look forward to further correspondence.

- Mark Hydeman

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exiting purposes in ~~Chapter 10 of the UBC/CBC~~. For spaces with fixed seating, the expected number of occupants shall be determined in accordance with ~~Chapter 10 of the UBC/CBC~~.

EXCEPTION to Section 121 (b) 2: Transfer air. The rate of outdoor air required by Section 121 (b) 2 may be provided with air transferred from other ventilated spaces if:

- A. None of the spaces from which air is transferred have any unusual sources of indoor air contaminants; and
- B. Enough outdoor air is supplied to all spaces combined to meet the requirements of Section 121 (b) 2 for each space individually.

(c) Operation and Control Requirements for Minimum Quantities of Outdoor Air.

1. **Times of occupancy.** The minimum rate of outdoor air required by Section 121 (b) 2 shall be supplied to each space at all times when the space is usually occupied.

EXCEPTION 1 to Section 121 (c) 1: Demand control ventilation. In intermittently occupied spaces that do not have processes or operations that generate dusts, fumes, mists, vapors or gasses and are not provided with local exhaust ventilation (such as indoor operation of internal combustion engines or areas designated for unvented food service preparation), the rate of outdoor air provided to an intermittently occupied space may be reduced if the ventilation system serving the space is controlled by a demand control ventilation device complying with 121 (c) 4, be reduced to 0.15 cfm per square foot of conditioned floor area if the ventilation system serving the space is controlled by a demand control ventilation device complying with 121 (c) 4.

EXCEPTION 2 to Section 121 (c) 1: Temporary reduction. The rate of outdoor air provided to a space may be reduced below the level required by Section 121 (b) 2 for up to five minutes each hour if the average rate each hour is the required rate.

NOTE: VAV must comply with Section 121 (c) 1 at minimum supply airflow.

2. **Pre-occupancy.** The lesser of the minimum rate of outdoor air required by Section 121 (b) 2 or three complete air changes shall be supplied to the entire building during the one-hour period immediately before the building is normally occupied.
3. **Required Demand Control Ventilation⁴⁹.** HVAC single zone systems with the following characteristics shall have demand ventilation controls complying with 121 (c) 4:
 - A. They have an outdoor air economizer; and
 - B. They serve a space with a design occupant density, or a maximum occupant load factor for exiting purposes in the CBC, greater than or equal to 25 people per 1000 ft² (40 square foot per person).
 - A. ~~That primarily serve areas with fixed seating and occupant densities less than or equal to 10 square foot per person, or identified in Chapter 10 of the UBC as either "Assembly Areas, Concentrated Use (without fixed seats)" or "Auction Rooms;" and~~

EXCEPTION 1 to Section 121 (c) 3 B: Classrooms are not required to have demand control ventilation.

EXCEPTION 2 to Section 121 (c) 3 B: Where space exhaust is greater than the design ventilation rate specified in 121 (b) 2 B minus 0.2 cfm per ft² of conditioned area.

EXCEPTION 3 to Section 121 (c) 3 B: Spaces that have processes or operations that generate dusts, fumes, mists, vapors, or gases and are not provided with local exhaust ventilation (such as indoor operation of internal combustion engines or areas designated for unvented food service preparation).

- B. ~~That have design outdoor air capacities equal to or exceeding 3,000 cfm.~~

4. **Demand Control Ventilation Devices, shall:**

⁴⁹ COMMENTARY: The justification for this change appears in Eley Associates, "Demand Controlled Ventilation (DVC)," *Measure Analysis and Life-Cycle Cost: 2005 California Building Energy Efficiency Standards, Part I*, April 11, 2002, p. 12-23. Presented at the April 23, 2002 workshop.

A. For each system with demand control ventilation, CO₂ sensors shall be installed in each room that meets the criteria of 121 (c) 3 B;

B. CO₂ sensors shall be located in the room between 1 ft and 6 ft above the floor;

C. Demand ventilation controls shall maintain CO₂ concentrations less than or equal to 600 ppm plus the outdoor air CO₂ concentration in all rooms with CO₂ sensors;

EXCEPTION to Section 121 (c) 4 C: The outdoor air ventilation rate is not required to be larger than the design outdoor air ventilation rate required by Section 121 (b) 2 regardless of CO₂ concentration.

D. Outdoor air CO₂ concentration shall be determined by one of the following:

- i. CO₂ concentration shall be assumed to be 400 ppm without any direct measurement; or
- ii. CO₂ concentration shall be dynamically measured using a CO₂ sensor located near the position of the outdoor air intake.

E. When the system is operating during hours of expected occupancy, the controls shall maintain system outdoor air ventilation rates no less than the rate listed in TABLE 121-A times the conditioned floor area for spaces with CO₂ sensors, plus the rate required by 121 (b) 2 for other spaces served by the system, or the exhaust air rate whichever is greater;

F. CO₂ sensors shall be certified by the manufacturer to have an accuracy of no less than 75 ppm, factory calibrated or calibrated at start-up, and certified by the manufacturer to require calibration no more frequently than once every 5 years.⁵⁰

~~A. Allow the rate of outdoor air to be reduced to 0.15 cfm per square foot of conditioned floor area if the demand control ventilation device indicates that the space conditions are acceptable; and~~

~~B. Be approved by the commission; and~~

~~C. If the device is a carbon dioxide sensor, limit the carbon dioxide level to no more than 800 ppm while the space is occupied; and~~

~~**NOTE:** control to 800 ppm is not required when the ventilation rate is equal to or greater than that required by Section 121 (b) 2.~~

~~D. Include a sensor for the device located (1) in the space; or (2) in a return air stream from the space with no less than one sensor for every 25,000 square feet of habitable space, or no more space than is recommended by the manufacturer, whichever is less.~~

5. Demand Control Ventilation Acceptance⁵¹. Before an occupancy permit is granted for a newly constructed building or space, or a new space-conditioning system serving a building or space is operated for normal use, all demand control ventilation devices serving the building or space shall be certified as meeting the Acceptance Requirements for Code Compliance. A Certificate of Acceptance shall be submitted to the building department that:

A. Certifies plans, specifications, installation certificates, and operating and maintenance information meet the requirements of Part 6.

B. Certifies that the demand control ventilation devices meet the requirements of Section 121 (c) 4.

(d) Ducting for Zonal Heating and Cooling Units. Where a return plenum is used to distribute outdoor air to a zonal heating or cooling unit which then supplies the air to a space in order to meet the requirements of Section 121 (b) 2, the outdoor air shall be ducted to discharge either:

- 1. Within five feet of the unit; or

⁵⁰ COMMENTARY: See Air Resources Board (dated December 20, 2002) and Taylor Engineering (dated December 24, 2002) letters.

⁵¹ COMMENTARY: This change results from NBI's recommendation: This proposed change requires demand control ventilation devices to be certified as meeting the Acceptance Requirements for Code Compliance.

Demand Controlled Ventilation (DCV)

Overview

Description

This initiative seeks to expand the current requirement for demand ventilation controls. Specifically, this initiative is designed to address the following issues:

- Extending the requirements for DCV §121(c)3 to less dense building occupancies.
- Determining the cost effective, system size threshold for the requirement.
- Updating the control requirements for CO₂ sensors based on the best information available in the research and standard communities.

Extending the requirements to cover multiple zone systems is also investigated, but there are several reasons that their inclusion is not recommended at this time:

- There are not adequate modeling tools or research to support this effort. The effectiveness of DCV in multiple zone systems depends strongly on the diversity of the spaces and the ability of the system to take advantage of recirculated air from over-ventilated spaces. The results will be very application specific.
- It requires direct digital control (DDC) at the zone level to work. Since there is no requirement in the standards for DDC controls, these controls would have to be cost justified along with the DCV system.
- Adequate existing guidelines do not exist on how to sequence the controls for the zone terminal units and outdoor air dampers in response to changes in the space CO₂ levels.

The current DCV requirement §121(c)3, which was adopted in the AB 970 standards, is limited to UBC “high density” occupancies and spaces with fixed seating with less than 10 ft²/person. The existing requirement is limited to systems that provide a minimum of 3,000 cfm outdoor air supply (OA) at design occupancy. Both of these limits are set higher than the cost effective threshold to provide the industry time to adjust to a new requirement for DCV. The life cycle cost study that was completed for the AB 970 requirement indicates that it might be cost effective for a wider variety of less dense occupancies such as classrooms, airport or train terminals, and others.

Three threshold occupant densities are of particular interest in this effort³:

1. 14 ft²/person covers the UBC classification for “high density” assembly spaces (Figure 1, usage category 3).
2. 30 ft²/person covers the UBC classification for less dense assembly spaces (Figure 1, usage category 4).
3. 40 ft²/person covers the UBC classification for classrooms (Figure 1, usage category 7).

These three thresholds represent half the occupant densities (i.e. half as many people) of the tables in Chapter 10 of the Uniform Building Code (UBC) for calculation of exiting requirements. Section §121(b)2B of Title 24 uses half of the UBC exiting occupant densities as the minimum occupant density for purposes of ventilation requirements. These three densities are of interest because they represent many typical assembly spaces including theaters, reception areas, ballrooms, stadiums, train and air terminals, and classrooms.

³ §121(b)2B refers to Chapter 10 of the UBC for calculation of the occupant density where fixed seating is not provided. “For spaces without fixed seating, the expected number of occupants shall be assumed to be no less than one half the maximum occupant load assumed for exiting purposes in Chapter 10 of the UBC.” The three thresholds used in this study are the thresholds for the three densest occupancies in this section of the UBC.

USE ¹	MINIMUM OF TWO EXITS OTHER THAN ELEVATORS ARE REQUIRED WHERE NUMBER OF OCCUPANTS IS AT LEAST	OCCUPANT LOAD FACTOR ² (square feet) × 0.0929 for m ²
1. Aircraft hangars (no repair)	10	500
2. Auction rooms	30	7
3. Assembly areas, concentrated use (without fixed seats) Auditoriums Churches and chapels Dance floors Lobby accessory to assembly occupancy Lodge rooms Reviewing stands Stadiums Waiting area	50	7
4. Assembly areas, less-concentrated use Conference rooms Dining rooms Drinking establishments Exhibit rooms Gymnasiums Lounges Stages	50	15
5. Bowling alley (assume no occupant load for bowling lanes)	50	4
6. Children's homes and homes for the aged	6	80
7. Classrooms	30	20
8. Congregate residences	10	200
9. Courtrooms	50	40
10. Dormitories	10	50
11. Dwellings	10	300
12. Exercising rooms	50	50
13. Garage, parking	30	200
14. Hospitals and sanitariums— Health-care center Nursing homes Sleeping rooms Treatment rooms	10 6 10	80 80 80
15. Hotels and apartments	10	200
16. Kitchen—commercial	30	200
17. Library reading room	50	50
18. Locker rooms	30	50

Figure 1 - UBC Exit Density Requirements

In order to evaluate this measure, cost data is collected on demand-based ventilation controls and simulated economizer performance with and without DCV for several different assumptions of occupant density and across all climate zones. DCV is simulated by having the minimum outdoor air supply modulate with the occupancy to maintain 15 cfm/person at all times. The simulated base case of no DCV has a minimum outdoor air supply fixed at 15 cfm/person based on design occupancy.

The analysis shows that DCV is cost effective in the target occupant densities where airside economizers are required for single zone systems. As previously noted, an extension to multiple zone systems is not being proposed at this time.

In addition to the analysis for cost effective thresholds for DCV, documented research and issues support the removal of the 800 ppm set point for CO₂-based DCV systems. Research consensus is that higher levels of CO₂ are not a health hazard and that the CO₂ set point should be the equivalent of 15 cfm/person, a slightly higher number. Although a higher set point will result in a higher level of contaminants in the space, the

greater of two minimums, a) the threshold outside air minimum of 15 cfm/person, and b) the minimum set point for building based contaminants, is considered to be reasonable by relevant code and standard authorities (ASHRAE 62-2001, ASHRAE 90.1-1999, and the 2000 International Mechanical Code).

Benefits

DCV saves energy and reduces peak demand. DCV dynamically reduces the amount of outside air when fewer than the design number of people are in a zone. An additional benefit of DCV is the ability of occupants and system operators to monitor CO₂ concentration in a zone and therefore receive feedback on HVAC system ventilation performance.

Environmental Impact

Beneficial environmental impacts are reduced electricity (energy and demand) and natural gas consumption.

When properly tuned, DCV insures that code minimum ventilation rates are maintained at all times. It acts to reduce over-ventilation of spaces when they are not fully occupied.

DCV systems increase the concentration of bioeffluents and building-borne contaminants in the space when partially occupied. However, as documented in this study, these contaminant levels are maintained at acceptable concentrations based on research, and consensus of code and standard organizations.

Type of Change

The proposed measure is a modification of an existing mandatory measure, §121(c)3. It extends the current coverage of the DCV requirement to include a wider range of occupancies. It also relaxes the ventilation requirements for CO₂-based DCV systems, which improves energy savings.

The change requires minimal modification of the standards, nonresidential manual, and ACM modeling procedures.

The changes to the standards are described below. The ACM change models a scheduled outdoor air minimum position based on 15 cfm per person and the occupant schedule. The nonresidential manual updates describe how to implement demand-based ventilation controls with single zone system economizers. The nonresidential manual will also provide guidance on how to select the design set points for these controls, performance verification during startup, and field calibration of the sensors.

Measure Availability and Cost

CO₂ sensors and controls are readily available from several manufacturers in quantities to satisfy current demand. Because market penetration to date has been fairly limited, the industry was surveyed to determine the difficulty of scaling up production. It was found that with a lead time in the three to six month range, manufacturers could produce sensors far in excess of California's requirements.

CO₂ sensors and controls are integrated into thermostats and economizers as OEM products by some of the major air-conditioning manufacturers. Sensors available on the market today have a self-calibrating feature and are inherently stable enough to ensure that recalibration is required at intervals exceeding five years⁴. One sensor manufacture has bundled their sensor into temperature sensors for packaged equipment and into economizer controllers. CO₂ controls are available as a factory-installed option on packaged rooftop equipment from several manufacturers, including all the major manufacturers.

CO₂ sensors are primarily electronic devices with microprocessors that are very simple to produce and can be set up at almost any good electronics manufacturing company. Build time and calibration takes a few hours. At least three large, well-financed companies are primary manufacturers involved in this market and can respond easily to an increase in sensor demand resulting from this requirement. These manufacturers provide product to all major HVAC and controls companies, who in turn, will be placing orders well in advance of this

⁴ One manufacturer maintains that this self calibration feature will indeed last the life of the sensor and control. They are considering extending their warranty to the life of the system.

requirement. According to the largest commercial manufacture, the most conservative lead-time on components is approximately three months. One manufacturer's parent corporation produces over 2,000,000 sensors annually. The electronics and optical elements for CO₂ and smoke detectors are very similar on a manufacturing basis. That manufacturer has four world-wide plants and plenty of excess capacity – with six to eight months warning, they can easily produce hundreds of thousands of sensors, far in excess of California's requirements.

In calculating the life cycle cost, the baseline comparison condition is no DCV device and a fixed minimum outside air quantity. As mentioned above, market penetration to date is fairly limited. Therefore, the proposed requirement significantly increases market penetration and is likely result in both cost reductions and advancements in technology.

Several DCV system vendors provided for the most recent cost data on DCV kits for several sizes of packaged rooftop equipment. Three packaged rooftop equipment vendors responded with incremental costs.

Table 9 - Vendor Cost Data for CO₂ Based DCV as an Addition to Airside Economizers

	Incremental Cost (\$/system)	Incremental labor (hrs/system)
Vendor A	\$310	0.5
Vendor B	\$400	0.5- 1.0
Vendor C	\$700	8-16

Vendor C is an outlier. Their prices are artificially high due to their unfamiliarity with these systems. Given the responses from Vendors A and B as well as the expected reductions in cost and labor as usage and familiarity grow, a reasonably conservative estimate of the incremental first cost is as follows:

Table 10 – Estimated Incremental First Cost

Parts: \$300 (+25% contractor markup)	\$375
Labor: Two hours @ \$100/hr	\$200
TOTAL	\$575

Although Vendors A and B estimated between half to one hour of labor for installation and start-up, labor in this table is conservatively estimated at two hours.

Technology Measures

Useful Life, Persistence and Maintenance

According to two manufacturers, their product will last 15 years. They claim that the calibration of the sensor is accurate over the life of the sensor, although it is only currently warranted for five years. Several manufacturers have a recommended calibration interval of five years or greater.

CO₂ sensors are normal electronic devices that have a useful lifetime similar to other electronic base sensors and controls. Using readily available commercial components, one manufacturer recently completed a mean time between failure (MTBF) analysis for a customer and found it to be 15 years. Sensor stability and self-calibration features integrated into sensor design prevent degradation of the sensor. For sensors without this feature, the manufacturers provide calibration procedures, recommended calibration schedules, and calibration kits.

Many CO₂ sensors devices have integrated some level of self-diagnostics to identify potential problems. The output of the microprocessor-based CO₂ sensors can be analog or digital. An example of a self-diagnostic failure indication from an analog sensor (the range of which is 0-10 VDC or 4-20 mA) would be either sending out the maximum signal or providing zero output. Since ambient CO₂ levels are always above 350 to 400 ppm, a zero signal is an automatic indication of a sensor failure. When connected to a building control system or air handling unit controller, this zero signal can be interpreted as a fault, with the appropriate action then taken. A failure indication from a digital communicating sensor (e.g., Lonworks) is either a fault signal or a failure to communicate, both of which allow for the appropriate response from the ventilation control system.

Given the number ways different control systems handle the non-standardized CO₂ signals, any fail-safe considerations have to be integrated into the controller. Many controls companies have already integrated an automated control systems response, as well as an alert for human intervention when a sensor appears to be providing incorrect readings.

Sensor failure is only an issue when the system is not in economizer mode, when sensor error would adversely affect indoor air quality. For example, if a space is heavily occupied but the sensor underestimates CO₂ concentration, then the system may not bring in adequate ventilation.

Although the description above focuses on how a CO₂ sensor may fail, CO₂ sensors can improve the overall functioning of a system by indicating failure of other mechanical system components, such as a frozen outside air damper or leaking furnace heat exchanger.

Performance Verification

The TAB contractor calibrates the controls and damper positions during startup. Kits with calibrated CO₂ concentrations are available at approximately \$100 each that can be used to field calibrate the sensors if necessary. These kits are available from a number of sources including the DCV manufacturers, industrial sensor manufacturers, and industrial gas companies. At least two manufacturers, Honeywell and Telaire, have sensors with a maximum guaranteed drift over a five-year period. These sensors are factory calibrated.

The performance verification paper proposes adding two requirements to improve the performance of DCV devices:

- Certification by either the manufacturer or installing contractor that the CO₂ sensor has been calibrated on installation.
- Provision of recommended calibration procedures and intervals from the manufacturer.

Cost Effectiveness

This measure is justified through a detailed life cycle cost analysis. See the life cycle cost analysis section below.

Analysis Tools

DOE-2.2 with the eQuest interface is used to analyze this measure.

Relationship to Other Measures

This measure is tied to the prescriptive requirement for airside economizers (§144(e)). The incremental cost of implementing this measure assumes that the cost for the outside air damper actuator and minimum position potentiometer are already included in the base case. These items are an integral part of an airside economizer.

Methodology

Simulation Using DOE-2 Office Model in California

Ninety-six simulations were performed to cover all the permutations of the climate, density, and minimum outside air control variables:

- Sixteen California climate zones.
- Three occupant densities:
 - 14 ft²/person (Title 24 ventilation density corresponding to UBC high density classification).

- 20 ft²/person (This was a mistake, as it was supposed to be 30 ft²/person corresponding to the UBC less dense assembly space classification. Since the results were cost effective at 40 ft²/person, this point is not significant).
 - 40 ft²/person (Title 24 ventilation density corresponding to UBC classroom classification).
- Two outside air schemes: DCV versus Fixed Minimum.

The eQuest interface generates a Title 24 (2001) compliant building with schedules based on the ACM manual.

Modeling Assumptions

- A 45 ft X 45 ft interior zone space with no windows, floor or roof load. Since the only difference between the base case and DCV runs is the minimum outdoor air set point, exterior loads are not a factor in the savings. The economizer in each case is fully functional. The only load that differs between the runs is the heating and/or cooling required for the different outside air ventilation rates. The dampers are modeled at minimum position unless the CO₂ sensor high limit switch has triggered or the economizer carries a greater percentage of the cooling load.
- Occupancy schedule. See discussion below.
- Minimum outside air. Two cases are run for each density:
 - No DCV – The minimum damper position is fixed at 15 cfm/person times the design occupancy
 - DCV – The minimum damper position is fixed at 15 cfm/person times ½ the design occupancy. Refer to the discussion below about occupant diversity and schedules.
- Lighting peak power of 1.5 W/ft². This is the ACM default for conference centers. LPD is varied each hour and day of the week using the ACM nonresidential lighting schedule. This schedule has the lights at 90% for most of the time.
- Equipment peak power of 1.0 W/ft². This is the ACM default for conference centers. The EPD is varied each hour and day of the week using the ACM nonresidential equipment schedule.
- Zone heating set point of 70°F with a 55°F setback, scheduled per the ACM nonresidential heating schedule.
- Zone cooling set point of 74°F with a 95°F setup, scheduled per the ACM nonresidential cooling schedule.
- System operation from 6 AM to 9 PM weekdays, 6 AM to 3 PM Saturdays, and off on Sundays, per the ACM non-residential fan schedule.
- A single zone served by a packaged single zone (DOE-2 type PSZ) unit with a 57°F minimum supply air temperature and a constant-volume draw-through fan.
- Cooling EIR, furnace HIR and fan power rating are all defaulted to Title 24 minimums.
- Fixed dry-bulb economizer with dry-bulb high limit set to 75°F.
- Cooling capacity is auto-sized with a 1.10 sizing ratio.
- Supply CFM is calculated based on steady-state design LPD, EPD and peak occupancy.
- Thermostat throttling range = 4.0. This is the ACM default for this system type.
- ACM default mass assumptions.

Occupancy Schedule

A number of occupancy schedules from ASHRAE Standard 90.1-1999 (public review draft 1), Title 24 ACM manual, and library schedules from the eQuest program are investigated. These are detailed below. For each of these schedules, the average occupancy is examined. The average occupancy varies from 40% to 70%. Since this measure will cover facilities that are likely to have their peak occupancies at different times of the

day (and during different utility rate periods), the conservative assumption of using a flat occupancy schedule of 50% full occupancy during all hours of operation is used.

The examined schedules include the following:

- ASHRAE 90.1-1999 Schedule "C" (used for museum general exhibition, theater auditorium seating area, theater lobby, supermarket, library, etc.). During the hours of fan operation, this schedule has an average occupancy of 50%.
- ASHRAE 90.1-1999 Schedule "I" (used for assembly, religious, theater performing arts seating, etc.) During the hours of fan operation, this schedule has an average occupancy of 54%.
- ASHRAE 90.1-1999 Schedule "B" (used for hotel banquet, motel dining, cafeteria, etc.) During the hours of fan operation, this schedule has an average occupancy of 51%.
- ASHRAE 90.1-1999 Schedule "D" (used for classroom, laboratory, etc.) During the hours of fan operation, this schedule has an average occupancy of 52%.
- eQuest – Secondary School Schedule. During the hours of fan operation, this schedule has an average occupancy of 41%.
- ACM Nonresidential Occupancy Schedule. This schedule only achieves 50% peak occupancy at any time and 35% average occupancy at all "normally occupied" times but is multiplied by the full UBC exiting density. Since the three threshold occupant densities are based on half the UBC exiting density numbers, the ACM schedule is rescaled by a factor of two. The resulting average occupancy is 70%.

All of these schedules are compared in Figure 2 below.

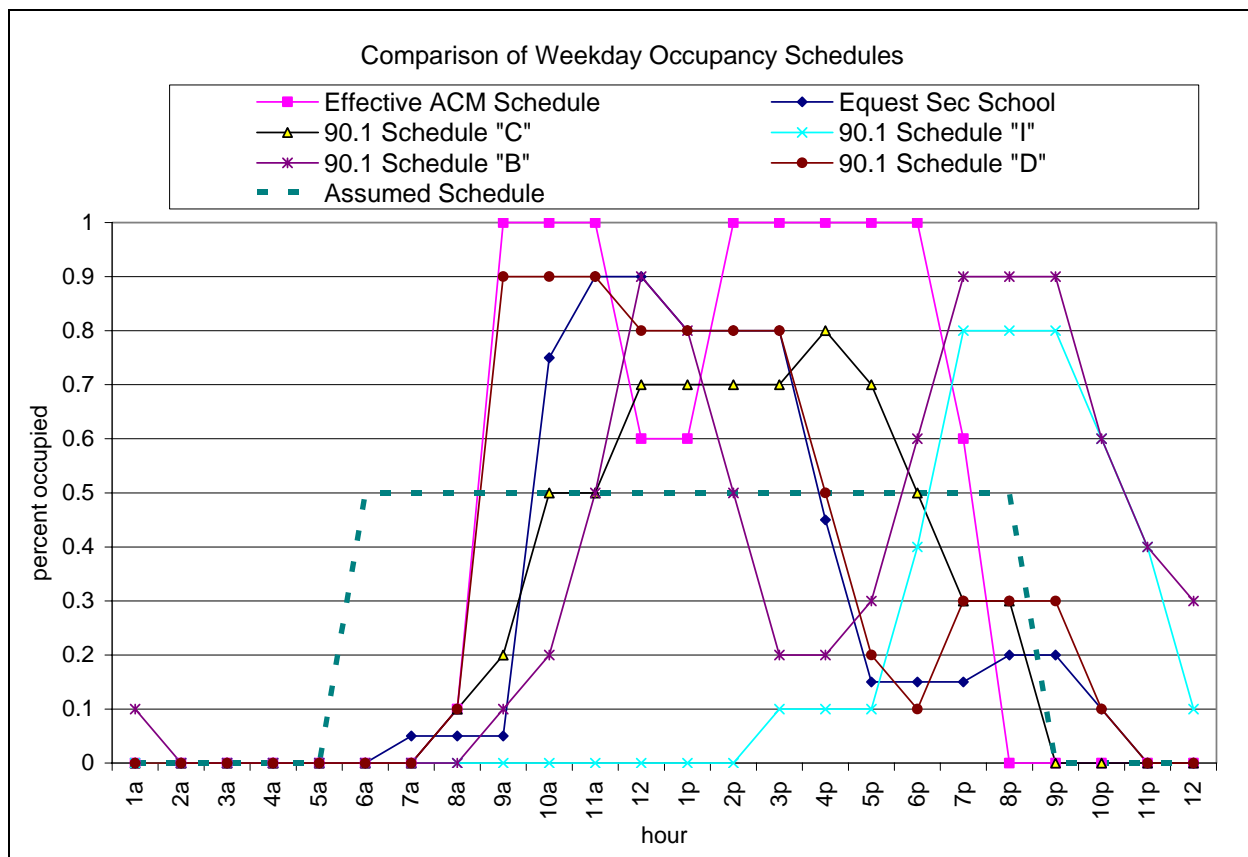


Figure 2 - Comparison of Schedules

Economic Criteria

The annual heating and cooling energy amounts for each run are converted to a net present value using the CEC standard amounts listed below. These data are taken from the "Utility Cost Forecasts, Years 2005 through 2035" document provided by Eley Associates.

- \$1.37 as the present value of a kilowatt-hour saved over a 15-year life.
- \$7.30 as the present value of a therm saved over a 15-year life.

The breakpoint where DCV becomes cost effective is the point at which the net present value of the energy savings exceeds the incremental first cost.

It is possible that a time-dependant valuation (TDV) analysis (as opposed to non-TDV approach used in this analysis) would show that DCV is even more cost effective because much of the potential benefit of DCV comes at the hottest periods of time. A non-TDV analysis is used to be conservative.

Results

Simulation and LCC Results

The results of the analysis for single zone HVAC systems are shown in Figure 3, Figure 4, and Table 11 below. Figure 3 and Figure 4 are the same results presented in different units. The results indicate that DCV systems are cost effective in all climates on single zone systems whenever airside economizers are required if the design area per person is 40 ft²/person or less (i.e. design minimum outdoor air \geq 0.375 cfm).

Figure 3 and Figure 4 show the life cycle cost analysis breakpoint for each of the 16 climate zones for each of the three occupant densities (14 ft²/person, 20 ft²/person, and 40 ft²/person). The horizontal axis is the occupant density expressed either in ft²/person (Figure 3) or the equivalent design ventilation in cfm of outside air per ft² of space at 15 cfm per person (Figure 4). The vertical axis is the AC unit size expressed either in the zone size (Figure 3) or design cfm of outside air (Figure 4). In addition to the results for the 16 individual climates, a dashed line indicates the weighted average of the results of all climate zones. The weighting factors are based on projected new construction (AB970 Impact Analysis Report).

The solid line at the top of each figure shows the approximate boundary of the existing air-side economizer requirement based on an internal zone. This line would be lower for a space with external loads. The small solid line in the upper right hand corner of each graph represents the current requirement for DCV in the AB970 standards.

Table 11 presents the simulation results in tabular format. For each climate zone, there are 16 columns. The first three columns present the cooling energy savings from DCV in kWh/ft² for each of the three occupant densities. The next three columns present the heating savings in therms/ft². The next three columns present the present value of the energy cost savings in \$/ft². The next two groups of three columns present the life cycle cost thresholds expressed in ft² of space and total HVAC system outdoor air, respectively. The final column presents the climate construction weights from the AB970 Impact Analysis Report.

In order to review the cost effectiveness implications of the figures, one example from Figure 3 is examined. In climate zone 6 (CZ6) and at a density of 14 ft²/person, as long as an economizer is already in place (prescriptive requirement and modeling assumption), the DCV is cost effective in all spaces larger than about 600 ft². However, the economizer is required only according to §144(e) and only above approximately 1,800 ft². Therefore, because benefiting from DCV requires having an economizer in place, the recommended standard needs to be relaxed to requiring DCV at the point that an economizer is required.

All of the climate zones are cost effective at zone sizes below the approximate economizer cutoff for 14 and 20 ft²/person densities. Similarly, 14 of the climate zones and the results of the weighted average climate zone are cost effective at 40 ft²/person. Two climate zones have DCV breakpoints very near the approximate economizer cutoff and are at the margin of cost effectiveness.

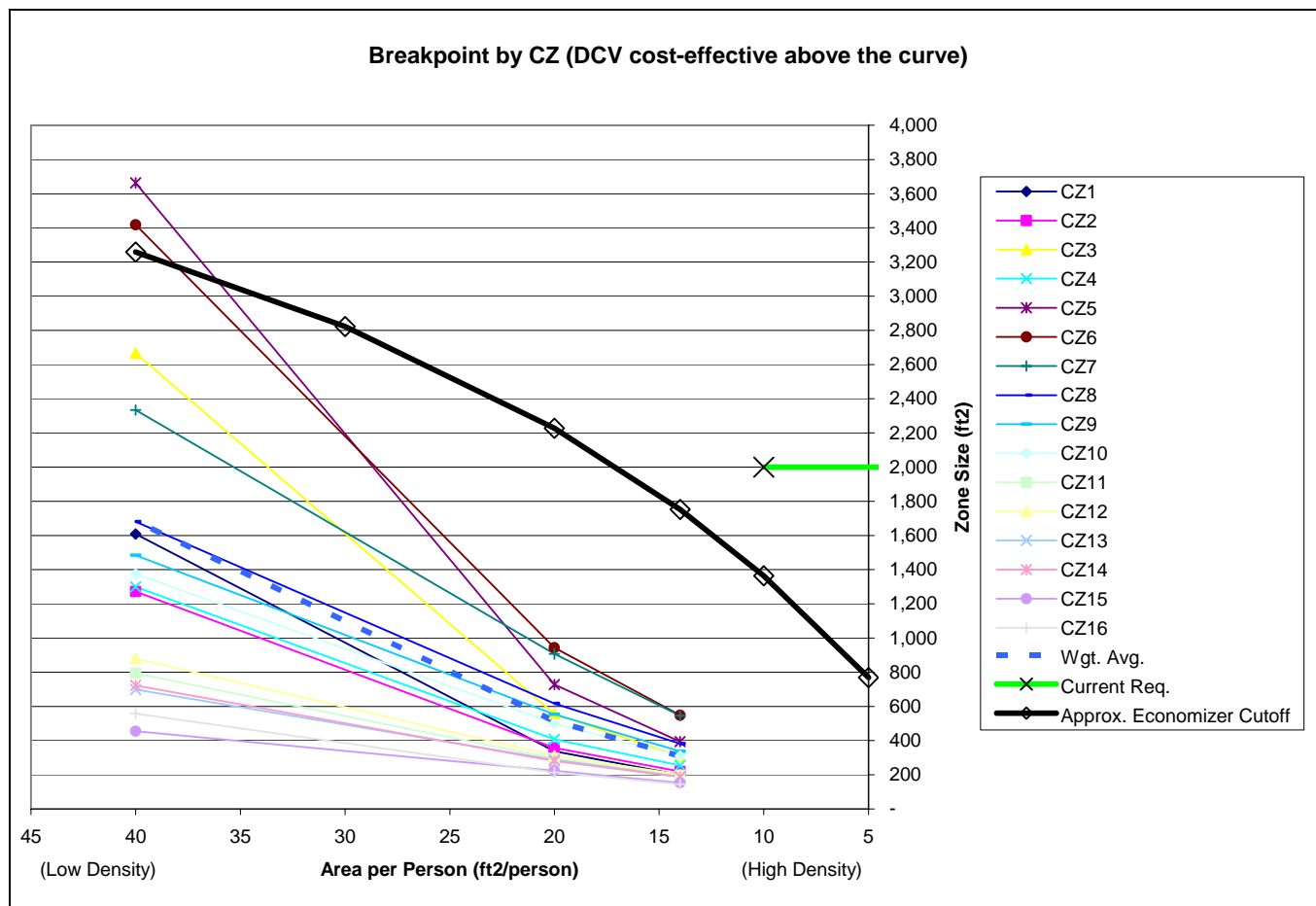


Figure 3 - Cost Effective Breakpoints and Proposed Requirements as a Function of Zone Size and Occupant Density

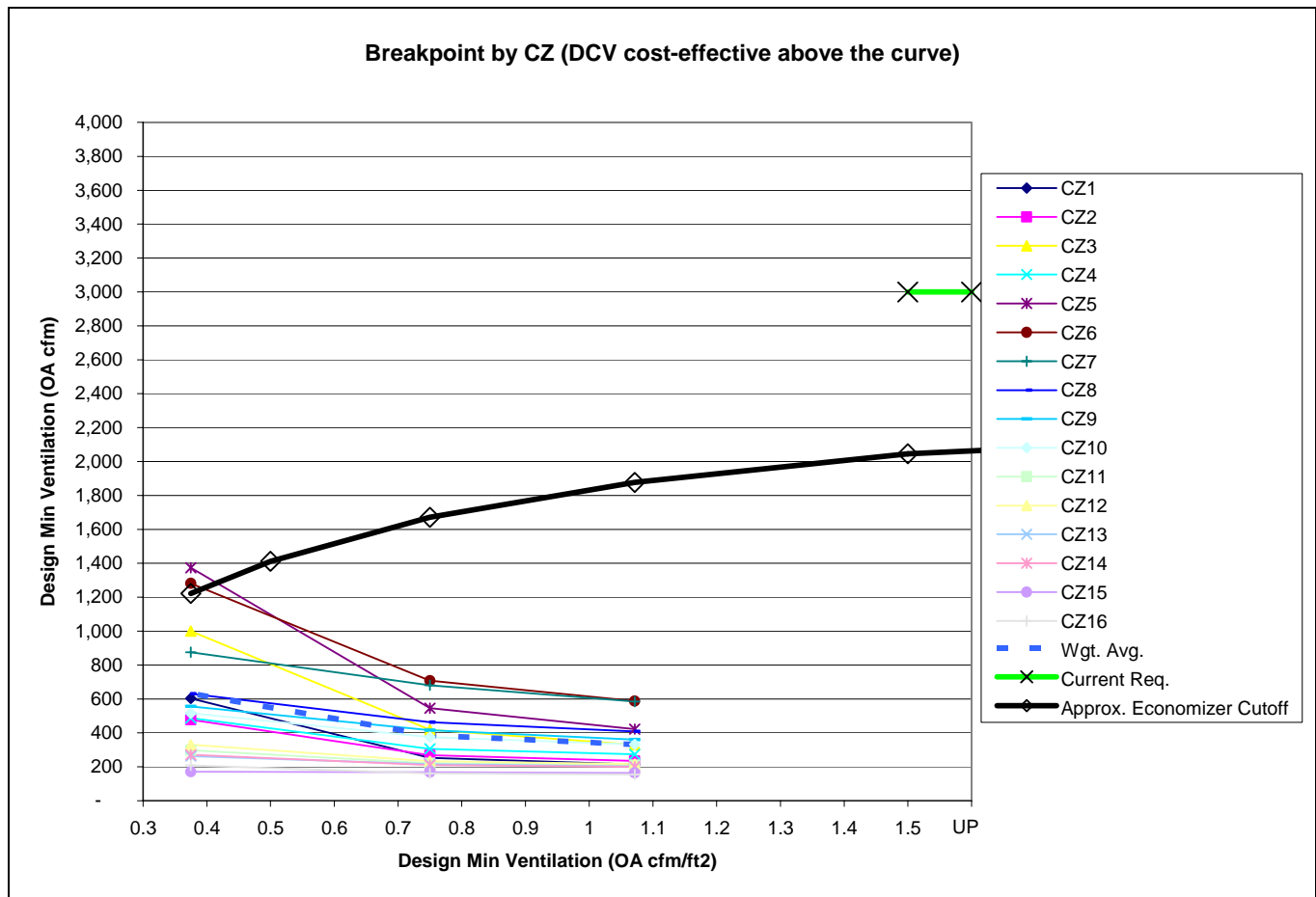


Figure 4 - Cost Effective Breakpoints and Proposed Requirements as a Function of HVAC System Design OSA and Design OSA Per Area of Space

Table 11 - Simulation Results in Tabular Format

CZ	Savings KWH/ft2			Savings therm/ft2			Savings\$/ft2			Breakpoint (ft2)			Breakpoint (osa)			Weights
	14	20	40	14	20	40	14	20	40	14	20	40	1.0714	0.75	0.375	
CZ1	0.00	(0.01)	(0.01)	0.40	0.24	0.05	\$ 2.89	\$ 1.71	\$ 0.36	199	337	1,609	213	252	603	0.3%
CZ2	0.27	0.16	0.06	0.31	0.19	0.05	\$ 2.63	\$ 1.61	\$ 0.45	219	357	1,272	234	268	477	7.0%
CZ3	0.16	0.10	0.05	0.42	0.23	0.04	\$ 3.28	\$ 1.82	\$ 0.32	175	317	1,782	188	237	668	15.9%
CZ4	0.37	0.26	0.14	0.24	0.15	0.04	\$ 2.26	\$ 1.41	\$ 0.44	255	408	1,299	273	306	487	7.1%
CZ5	0.05	0.02	0.01	0.19	0.11	0.02	\$ 1.46	\$ 0.79	\$ 0.16	394	727	3,663	422	546	1,374	1.9%
CZ6	0.18	0.13	0.07	0.11	0.06	0.01	\$ 1.05	\$ 0.61	\$ 0.17	548	944	3,418	587	708	1,282	6.0%
CZ7	0.32	0.22	0.13	0.09	0.05	0.01	\$ 1.05	\$ 0.63	\$ 0.25	545	907	2,335	584	680	875	7.5%
CZ8	0.51	0.36	0.20	0.11	0.06	0.01	\$ 1.51	\$ 0.93	\$ 0.34	382	617	1,680	409	462	630	8.8%
CZ9	0.64	0.44	0.23	0.12	0.06	0.01	\$ 1.71	\$ 1.04	\$ 0.39	336	553	1,484	360	415	557	10.4%
CZ10	0.69	0.47	0.23	0.13	0.07	0.02	\$ 1.86	\$ 1.15	\$ 0.42	310	500	1,374	332	375	515	8.4%
CZ11	0.65	0.44	0.21	0.28	0.19	0.06	\$ 2.93	\$ 1.95	\$ 0.73	196	294	792	210	221	297	1.4%
CZ12	0.54	0.37	0.18	0.29	0.19	0.06	\$ 2.85	\$ 1.85	\$ 0.65	202	311	880	216	233	330	14.5%
CZ13	1.03	0.72	0.36	0.23	0.14	0.05	\$ 3.05	\$ 2.00	\$ 0.82	188	287	699	202	215	262	6.0%
CZ14	0.86	0.59	0.29	0.26	0.17	0.06	\$ 3.08	\$ 2.05	\$ 0.80	187	280	723	200	210	271	2.4%
CZ15	2.40	1.69	0.87	0.07	0.04	0.01	\$ 3.77	\$ 2.57	\$ 1.26	153	224	455	164	168	170	2.0%
CZ16	0.16	0.09	0.03	0.52	0.35	0.14	\$ 3.98	\$ 2.68	\$ 1.03	144	214	557	155	161	209	0.5%
Wgt. Avg.										289	476	1,545	309	357	579	

Recommendations

Proposed Standards Language

121(c)3 Required Demand Control Ventilation. HVAC single zone systems shall have Demand-Control Ventilation systems complying with 121 (c) 4 provided:

- A. They have an outdoor air economizer; and
- B. They primarily serve a single room with a design occupant density greater than or equal to 25 people per 1,000 ft² (40 ft²/person), or the room's occupancy type per Chapter 10 of the UBC is "Assembly Areas," "Concentrated Use (without fixed seats)," "Auction Rooms," "Assembly Areas, Less-Concentrated Use," or "Classrooms."

121(c)4 Demand-Control Ventilation systems shall:

- A. Be a CO₂ sensor that has an accuracy of no less than 75 ppm, that is factory calibrated or calibrated at start-up, and that requires calibration no more frequently than once every five years. The sensor shall be located in the room between 1 ft and 6 ft above the floor;
- B. Reduce outdoor air ventilation rates below the design outdoor air ventilation rate when the number of occupants in the space is below the design occupancy. The controls shall be set to provide no less than 15 cfm per person of outdoor air as calculated by Equation 1-X;
- C. Maintain outdoor air ventilation rates no less than the rate listed in Table 1-F times the conditioned floor area, regardless of occupancy, when the system is operating during hours of expected occupancy; and
- D. Supply the design outdoor air ventilation rate when the sensor fails or provides a reading out of normal range.

Equation 1-X

$$R_p = \frac{8,400 \times m}{C_R - C_{OA}}$$

where,

R_p = The rate of outdoor air per person (cfm/person)

m = The metabolic rate (1 met = 58.2 W/m²). The default metabolic rate is 1.2 mets.

C_{OA} = The outdoor air CO₂ concentration (ppm). The default outdoor air CO₂ concentration is 400 ppm.

C_R = The room CO₂ concentration (ppm) measured by the sensor.

Proposed ACM Language

The proposed ACM language is yet to be developed. It is recommended that systems with complying DCV controls be modeled with half of the design minimum outdoor air set point down to a floor of the cfm/ft² rates listed in Table 1-F. The same assumptions would be used in the base case building for systems that would be required to have DCV controls per the proposed Section §121(c)3.

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